THE PEDAGOGIC VALUE OF THE HISTORY OF PHYSICS[1]

"THE education of the child must accord both in mode and arrangement with the education of mankind as considered historically; or, in other words, the genesis of knowledge in the individual must follow the same course as the genesis of knowledge in the race." Such has been the teaching of theorists like Comte and Spencer; such has been the conviction of teachers like Pestalozzi and Froebel. This doctrine is far from self-evident, but *if* it applies to physics, then certainly the history of the science should receive greater attention.

Professor Ostwald of the University of Leipzig, the editor of the *Classics of the Exact Sciences*, emphasizes the importance of the history of science as follows: "While . . . the knowledge of science as it now exists is being imparted successfully, eminent and farsighted men have repeatedly been forced to point out a deficiency which too often attaches to the present scientific education of our younger talent. It is the absence of the historical sense and the want of familiarity with the great researches upon which the edifice of science rests."

Thus great writers on the philosophy of education as well as eminent scientific investigators have, in a general way, pointed out the value of a knowledge of the progress of science. The practical teacher will ask himself the practical question, exactly in what way will a knowledge of the history of physics aid in elementary teaching?

In the first place, *a knowledge of the struggles which original investigators have undergone leads the teacher to a deeper appreciation of the difficulties which pupils encounter.* The difference between mass and weight is a stumbling-block to beginners, and the instructor's patience is often taxed to the utmost. The great originators of mechanics — Galileo, Descartes, Leibnitz, Huygens

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—had no clear notion of mass. Weight and mass were taken interchangeably; the two terms meant one and the same thing. That there is a distinction between the two began to dawn upon the minds when it was discovered that the same body may receive different accelerations by gravity on different parts of the earth's surface. When Jean Richer in 1671 went from Paris to Cayenne in French Guiana to make astronomical observations, he found that his pendulum clock, which in Paris kept correct time, fell daily two and one half minutes behind mean solar time. It was shortened, but after his return to Paris it had to be let out again. The distinction between mass and weight was clearly perceived by Newton in his extension of the laws of dynamics to heavenly bodies.[1] On the same spot of the earth mass and weight are proportional to each other. This is not a self-evident fact; Newton proved it in course of a splendid series of tests on the pendulum. He says in his *Principia* (Book II, Prop. XXIV, Cor. 7): "By experiments made with the greatest accuracy I have always found the quantity of matter in bodies to be proportional to their weight."

That the difficulties which students encounter are often real difficulties such as the builders of the science succeeded in overcoming only after prolonged thought and discussion can be exemplified in many ways. Take the laws of motion, the true nature of "centrifugal force," the difference between force and energy, the explanation of the "force of suction," the difference between electric and magnetic phenomena, where is the teacher who, by a knowledge of the struggles undergone by the master minds, will not be impressed by a deeper sympathy with students who encounter "hard points" and are at first unable to master them? More than this, the way original thinkers leveled the barriers often suggests to the teacher good methods for removing those of the pupil. The pendulum at Cayenne was acted upon by forces to a less degree than at Paris, yet its mass was the same in both places; the mass was the same, but the weight was different.

While to the instructor the history of science teaches

[1] MACH, *Science of Mechanics*, transl. by T. J. McCormack, 1893, pp. 161, 251.

patience, *to the pupil it shows the necessity of persistent effort.* Newton began to think of gravitation in 1666, but that coquettish maiden, the law of inverse squares, long eluded him. Jacob waited for Rachel twice seven years; Newton waited for *his* Rachel nearly thrice seven years.

A third lesson to be drawn from historical study is *the necessity of checking speculation and correcting our judgment by continual appeal to the facts, as determined by experiment.* This lesson is as important to the young pupil as it is to the original investigator. Many a young girl first entering the laboratory is afraid of deadly shocks from a harmless Leclanchè cell. Let not the teacher attribute such preconceived notions to stupidity. Able minds have made just such mistakes. The great logician, Aristotle, walking up and down the paths near his school in Athens, came to the conclusion through some involved process of *a priori* reasoning that bodies fall quicker in exact proportion to their weight.[1] If it had only occurred to him to pick up two stones of unequal mass, and then drop them together, he could easily have seen that the one of, say, ten times the mass did not descend ten times faster. The experiment was omitted, and Aristotle never found out his error. Nor did the readers of his books for two thousand years, until finally Galileo ascended the leaning tower of Pisa and dropped iron balls of different weights to show that a light ball will fall with the same velocity as a heavy ball.

Another conspicuous instance of a great man whose judgment was untrained by habitual appeal to the facts was Descartes. When the Copernican theory was under disçussion it was claimed by many that, if the earth rotates and bullets are fired vertically upward, they must strike the ground far to the westward. Mersenne and Petit in France tried the experiment. But they were perplexed by an unexpected occurrence. They could not find their bullets at all! Descartes, the great French oracle of the time, was consulted, and he seriously replied that the bullets had received such intense velocity that they lost their weight and flew away from the earth. Such an absurd reply could never have come from experimenters like Galileo or Newton.

[1] *De Coelo*, Book III, chap. 2.

Another point which I desire to make is that *the history of science demonstrates the futility of the pedagogical theory, according to which the pupils in the laboratory should be made to re-discover the laws of nature.* If ever a teacher undertakes an impossible task, it is he who expects to bring his pupils to the point where they, in eight or nine months, will achieve what Galileo, Gilbert, Boyle, Guericke, Newton, and a host of others, by their united strength, have thought out only after a lifetime given to scientific work. In impracticability this Utopian scheme surpasses all others. Sir Thomas More was outclassed by him who originated this pedagogical theory.

Can we expect our students to discover the law of refraction, *i. e.*, the law that the ratio of *sin i* and *sin r* is constant? To be sure, we may let the student measure the angles of incidence and refraction and he will, perhaps, obtain the following data:

Angle of incidence: 0°, 12°, 20°, 40°, 60°, 70°.

Angle of refraction: 0°, 9°, 15°, 28½°, 41°, 45°.

From the first three pairs, says Dr. Recknagel in the *Zeitschrift f. Math. Unterricht*, the pupil might infer that the index is $\frac{4}{3}$ and is simply the ratio of the angles. But the last three pairs of angles show that the guess is wrong. However, "the right law is soon drawn out by questioning" (herausgefragt). No doubt it can, if *leading questions* are put, but usually in no other way. Let not the teacher be misled into the belief that by leading questions put to his pupils, he has gotten them actually to discover the law for themselves; they have merely taken the hint given them; they have *verified* the law, but not *discovered* it. We are not criticising the mode of procedure pointed out by Dr. Recknagel, but we object to the conclusion that the pupil has been led to make a discovery. History teaches us that four great scientists, whose minds had been richly endowed by nature and trained by years of scientific effort, endeavored to discover the law of refraction and *failed*. Ptolemy, one of the two greatest astronomers of antiquity, Al Hazen, the greatest Arabic physicist, Witelio, a prominent writer of the thirteenth century, and Kepler, the discoverer of "Kepler's Laws," vainly tried to establish the exact mathematical relation between the angles of inci-

dence and of refraction. Can therefore, youths with untrained minds accomplish on the spur of the moment what Ptolemy, Al Hazen, Witelio, and Kepler could not do after years of study? By chance they might, but only by chance. As a rule, the theory that the pupil should be made to re-discover the laws of nature leads either to failure or to deception. With even the brightest and maturest minds, discovery is largely a matter of accident. The history of science clearly proves this. The great Huygens recognized this when he said that a man capable of inventing the telescope by mere thinking and application of geometrical principles, without the concurrence of accident, would have been gifted with superhuman genius. In the schoolroom we cannot *wait* for such accident, though we should try to profit by it, if it does come.

I have pointed out how the history of physics disproves a certain pedagogical theory, how it shows the desirability of holding speculation in check by experimentation, how it emphasizes the necessity of patience on part of the teacher and perseverance on part of the student. I might have spoken of the great liberalizing effect of the view which it affords of the development of the human intellect. But with the practical teacher all these considerations dwindle into insignificance as compared with the aid to be derived from history as a stimulant, as a means of exciting interest. If a teacher creates a living interest in a subject, all other difficulties vanish. Before the introduction of the modern physical laboratory, physics was almost always a subject disliked by students. Even now it is not always popular. The number of students electing laboratory work at the University of Cambridge under James Clerk Maxwell was always small, Ritchie at the London University had comparatively few students. Biot in Paris had often not above half a dozen. Any remedy against such a condition of things must be hailed with joy. Of course, as Rowland says, "Some are born blind to the beauties of the world around them, some have their tastes better developed in other directions, and some have minds incapable of ever understanding the simplest natural phenomenon; but there is also a large class of students who have at least ordinary tastes for

scientific pursuits." Students of the last class may be drawn closer to physics by good laboratory courses and by an acquaintance with the great minds who developed the science.

Of course, historical matter is not to replace laboratory practice, or the discussion of theory; nor do I mean that elementary classes, whose time for the study of physics is already too limited, shall be burdened with a long and systematic course on the history of physics. Introduce historical matter incidentally and skillfully, and you will find it to be the honey which renders the bread and butter more palatable. Where is the student of physics who will not be fascinated by the experiments on air-pressure by Otto von Guericke and the illustrations accompanying the text? Here is a picture of fifty men pulling by ropes and vainly struggling to overcome the atmospheric pressure against one piston. There is an engraving representing eight pairs of horses, four pairs on each side, pulling for all they are worth to separate two huge Magdeburg hemispheres. It is of interest to know that Robert Boyle would probably not have discovered the law bearing his name, except for an absurd criticism made on some of his earlier researches by a would-be physicist. Linus, professor at Lüttich in Netherlands, declared that the air is very insufficient to perform such great matters as the holding up of a mercury column twenty nine inches high; he claimed to have found that the mercury hangs by invisible threads (funiculi) from the upper end of the tube and to have felt them when he closed the upper end of the tube with his finger. This criticism incited Boyle to renewed research and led him to the discovery of his law.

Again, let the student be drawn into the confidence of the historian and laugh with him at the undignified behavior of the Carthusian monks. In Paris a large number of them were formed into a line 900 feet long, "by means of iron wires . . . . between every two," and then Louis XV caused an electric shock from the newly invented Leyden jars to be administered to them. The whole company of austere monks, at the same instant of time, gave a sudden spring, and presented a sight decidedly ludicrous.

Quaint theories and hypotheses, now long forgotten, often

possess peculiar charm. When the pupil has acquired some knowledge of the spectrum, can he fail to be interested in some of the speculations of Newton? How Newton carried on his experiments, not in a public laboratory, but at his chamber in Cambridge; how he introduced light into the darkened room through a small circular hole, passed it through a prism, and then beheld the display of colors on the wall. "Comparing the length of this colored spectrum with its breadth," says Newton, "I found it about five times greater; a disproportion so extravagant that it excited me to a more than ordinary curiosity of examining from whence it might proceed."[1]

Newton showed that this phenomenon was due to the fact that some rays are more refrangible than others, but before he hit upon the right explanation he advanced several hypotheses, only to find that each was disproved by the facts. One of these guesses is of particular interest, as it shows that Newton's profound mind had dwelt upon a subject prominent in modern athletics, namely, the subject of "curved pitching." Surely the modern student would find it hard to guess what possible relation might be supposed to exist between the performance of a twirler on the diamond and optical theories. Newton said, "Then I began to suspect whether the rays, after their trajection through the prism, did not move in curve lines, and, according to their more or less curvity, tend to divers parts of the wall, and it increased my suspicion when I remembered that I had often seen a tennis ball, struck with an oblique racket, describe such a curve line." Newton's idea was that the little particles supposed to constitute light received a circular motion in passing through the prism, and, meeting resistance in the ether, would curve around during their passage from the prism to the wall. Some particles receive a greater rotation and curve around more than others. Those bending around farthest constitute the violet rays; those deviated least make up the red rays.

Will students be interested in details of this sort? So far as I know, the testimony of teachers who have tried it is unanimous. The pupil begins to feel that he has a personal acquaint-

[1] *Phil. Trans.* Abr., Vol. I. p. 128.

ance with the great men of science. He is charmed with reminiscences about them, with their hopes, struggles, disappointments. They appear to him no longer as irresistible, superhuman heroes, but as human beings, liable to perplexity and failure. During this historical reading the pupil unconsciously acquires a greater mastery of the subject itself. Not infrequently the enthusiasm of the investigator is transmitted to the pupil.

Plutarch tells us that Archimedes was continually accompanied by an invisible siren whose bewitching music caused him to forget the troublesome affairs of life, and inspired him for the study of great themes and the discovery of truth. These same siren melodies have charmed Galileo, Newton, Fresnel, Helmholtz. Let our pupils get closer to these master-minds, and they, too, though only feebly, perhaps, may be brought under the enchanting spell.

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